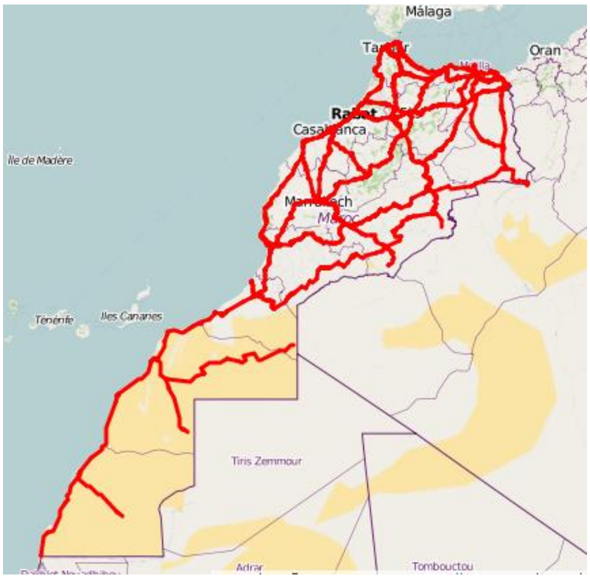
Département Génie Civil

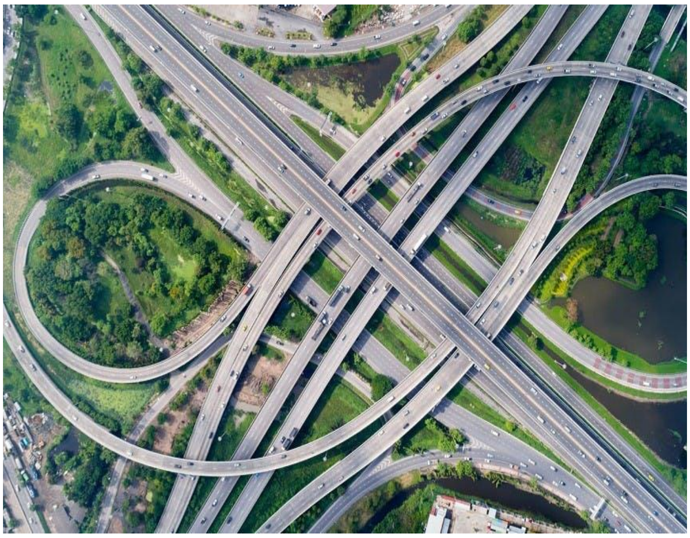
Deuxième année

Ecole Mohammadia d'Ingénieurs
المدرسة المحمدية للمهندسين

Optimization in construction's problems (ACO method)

Roads construction:





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Introduction

Optimization is a systematic process using design constraints and criteria to allow the designer to locate the optimal solution. The purpose of optimization is to achieve the “best” design relative to a set of prioritized criteria or constraints.

In an engineering design approach, both analysis and optimization are used before any prototype work starts. The general purpose of this topic is to integrate the concept of optimization in a road construction project.

Road design consists of the outline and the design of a road construction project. It includes 2D and 3D schematic drawings and renderings, recommendations for construction materials, a detailed survey of the project site, and a plan for the road construction process.

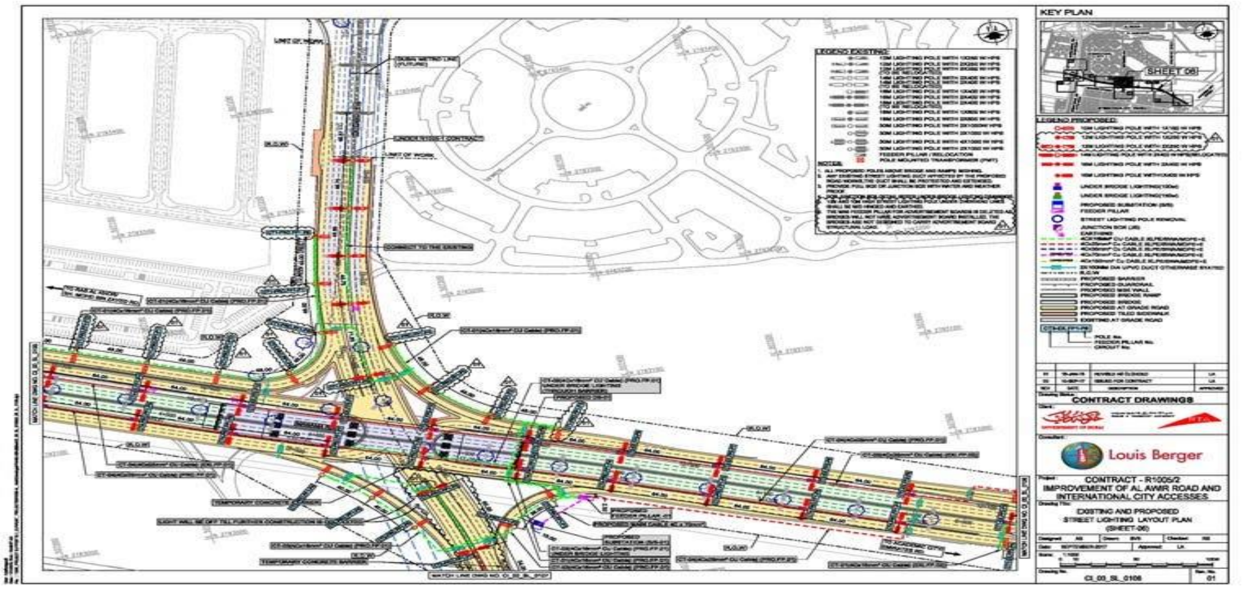

KEY PLAN
SHEET 06
LEGEND EXISTING
LEGEND PROPOSED
CONTRACT DRAWINGS
Louis Berger
CONTRACT - R1005/2
IMPROVEMENT OF AL AWIR ROAD AND INTERNATIONAL CITY ACCESSES
EXISTING AND PROPOSED STREET LIGHTING LAYOUT PLAN (SHEET-06)

Figure 1: Road Construction Plan

Choice Explanation

In civil engineering, we need to build a road to connect two points or more. During the preliminary study of a road construction, we need to find a better possibility to connect the different points.

In terms of efficiency and cost, finding the best path will make the task of the road construction project easier.

The reason why I chose optimization using the ACO algorithm (Ant Colony Optimization) is because it is a technique that presents a lot of benefits in terms of road design and allows more flexibility during construction work.

Problematic

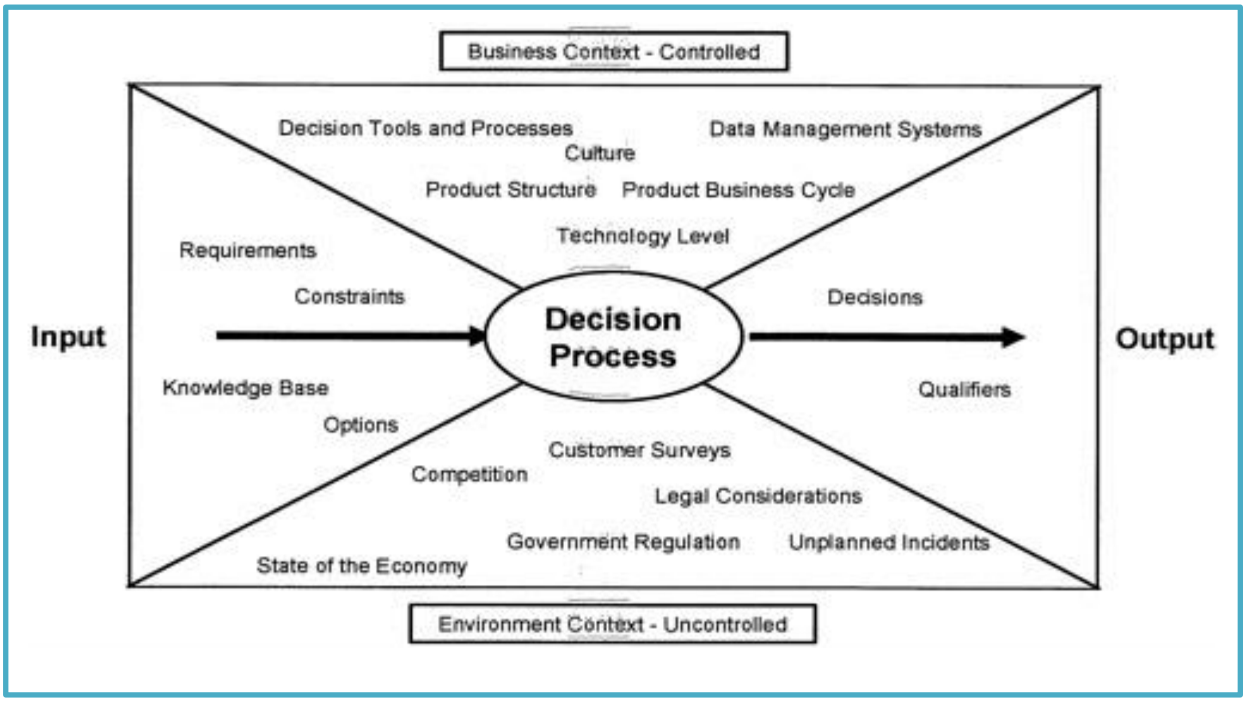
The history of roads covers a period that begins with the sedentarization of man. Also, there is an infinite number of possibilities to link different regions by a road. Thus, is it necessary to go through all the possibilities? Or we must find a way that will get us out of this puzzle?

Furthermore, during the construction period, we need to move equipments and materials to carry out the project. So, how can we use the ACO Algorithm for this matter? What are the points to take into consideration to make the best decision?

Decision Making in Construction

The design and construction process is very complex. Even with a careful control and supervision, it is not allowed to make changes. Thus, making a good decision is crucial. And a successful engineer will always have to take a precise decision.

The role of decision making in an engineering design context can be defined in several ways. To have as a result a good decision, it is necessary to analyze the whole environment of the problem; the decision process is influenced by sets of conditions shown in this figure.



The most important thing that should not be forgotten during construction is to take care of nature and not destroy forests and pollute the environment.

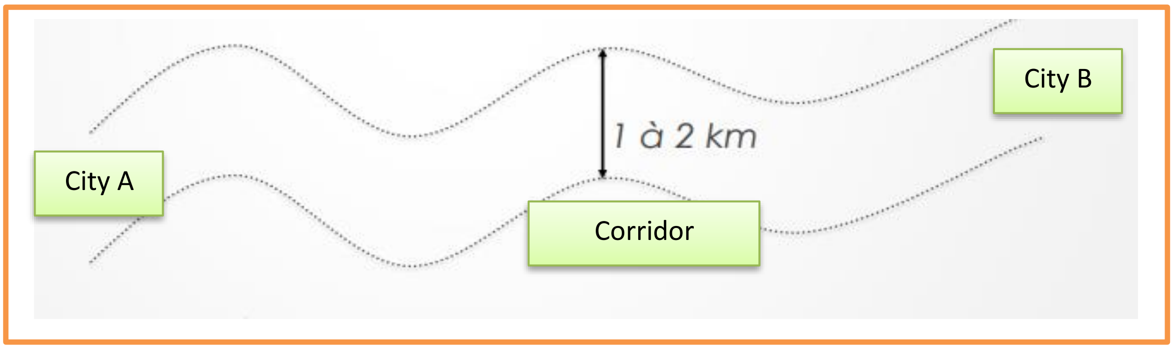
Steps of a road study

Road studies are divided into three main phases:

I. **Funding identification:**

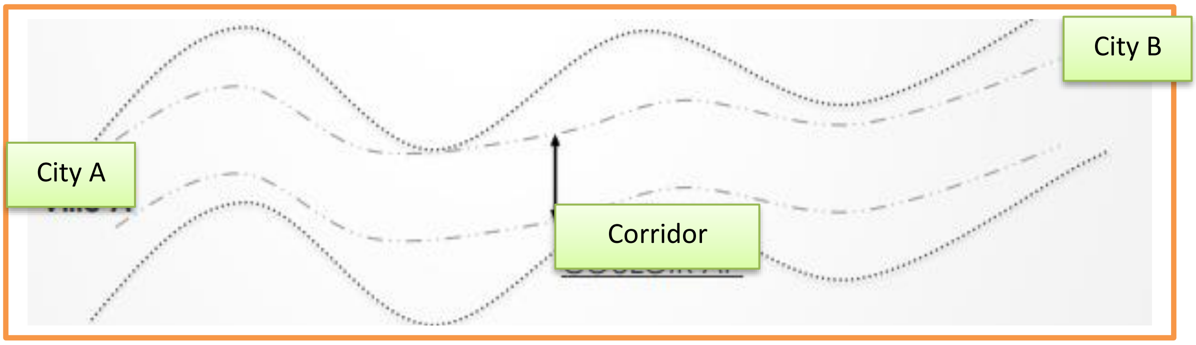
During this study, we identify - after comparison of potential variants - the passage corridor of the road. The passage corridor is in this case a strip of land ranging from 1 to 2 km in width and where the axis in plan of the road will be drawn.

Here we can see the benefits of ACO algorithm (choosing the optimum path)



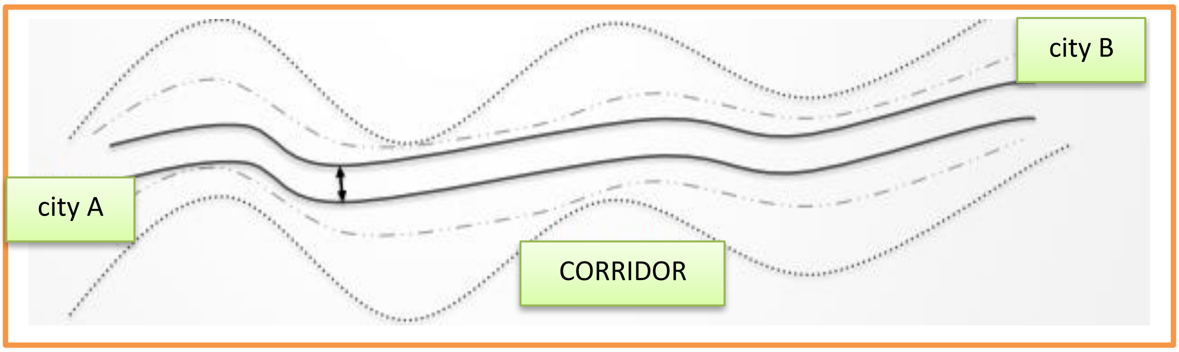
II. Preliminary Engineering:

This step aims to identify the main options of a road axis passage, define its geometry, and acquire a more precised cost estimate. The passage corridor is in this case a strip of land, 600m in width, and where the center line of the road will be drawn.



III. Execution study:

The purpose of this step is to prepare the execution and detailed plans, and to launch the project consultation. These plans will be used by companies to carry out the project. The passage corridor is in this case a strip of land, 300m wide.



Explanation of the ACO algorithm

Optimization methods:

Optimization methods can be classified into three methods: mathematical (also called exact), heuristic and metaheuristic.

1. ***Mathematical:***
   The exact methods can be useful for finding the global optimum. However, it suffers from some drawbacks – discrete decision variables and the exponential increase in solutions as the variables increase.

2. ***heuristic***
   The heuristic methods are fairly complicated to use, and they might be slightly problematic when it comes to complicated schedules. The use of heuristic methods does not guarantee finding the optimal solution of the given problem.

3. ***Metaheuristic***
   An effective method used for optimizations is the one using less time to solve the problem. Mathematical and heuristic methods don't allow to find solutions for complicated construction problems in a reasonable period of time. That's why metaheuristic algorithms seem to be the most appropriate measures for scheduling and task sequencing.

   Several metaheuristic algorithms are used to answer life problems. Among them: Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Genetic Algorithms (GA), Simulated Annealing (SA), Tabu Search (TS).

These algorithms are very useful when it comes to solving hard problems, because they allow to find suboptimal solutions in a reasonable period of time.

Now, we are going to focus on the Ant Colony Optimization.

What is Ant Colony Optimization?

In computer sciences and operation research, the Ant Colony Optimization algorithm (ACO) is a probabilistic technique for solving computational problems, which can be used to find good paths through graphs.

Ant Colony optimization algorithm is inspirited from the behaviour of real ant colonies. First, this algorithm was introduced by Marco Dorigo in 1942. This researcher of developments in artificial intelligence approached this algorithm to solve the Traveling Salesman problem.

The problem he was trying to solve is how can traveling salesmen sweep the maximum number of cities and choose the optimal path (the shortest and most cost-effective). So, Marco Dorigo followed and observed the behaviour of ants taking the road from their nest to their food location.

How does it work?

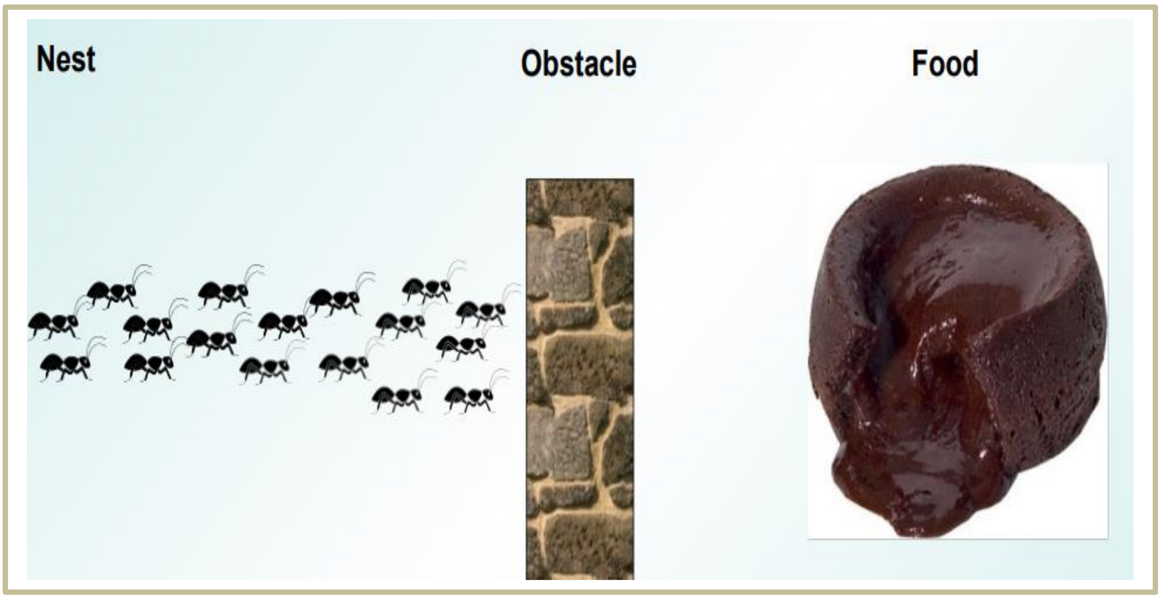
The algorithm is based on ants' behaviour when they try to find a route between its nest (anthill) and a food source.

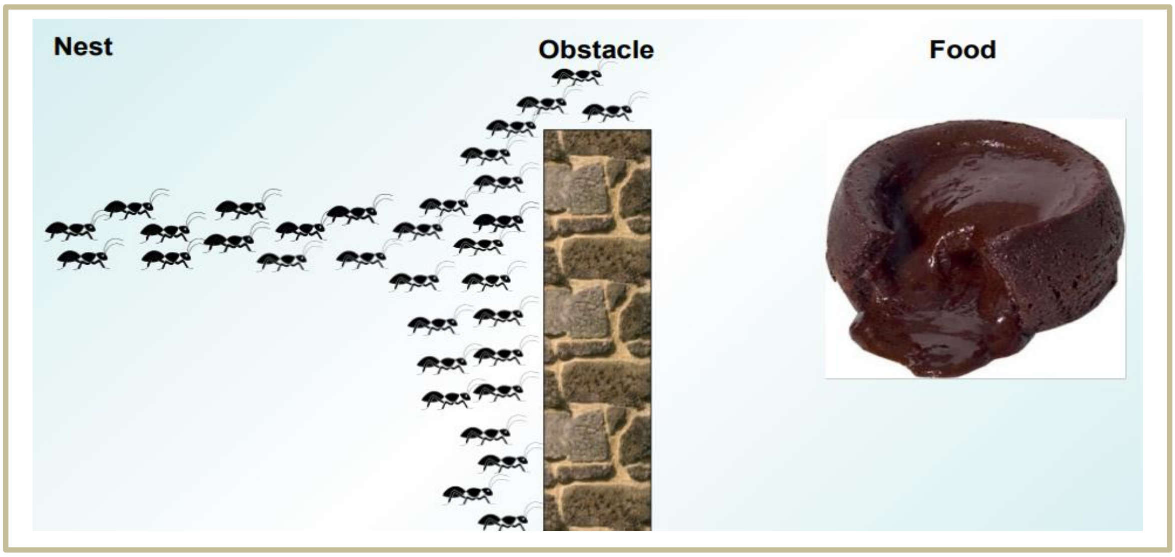
Ants' behaviour:

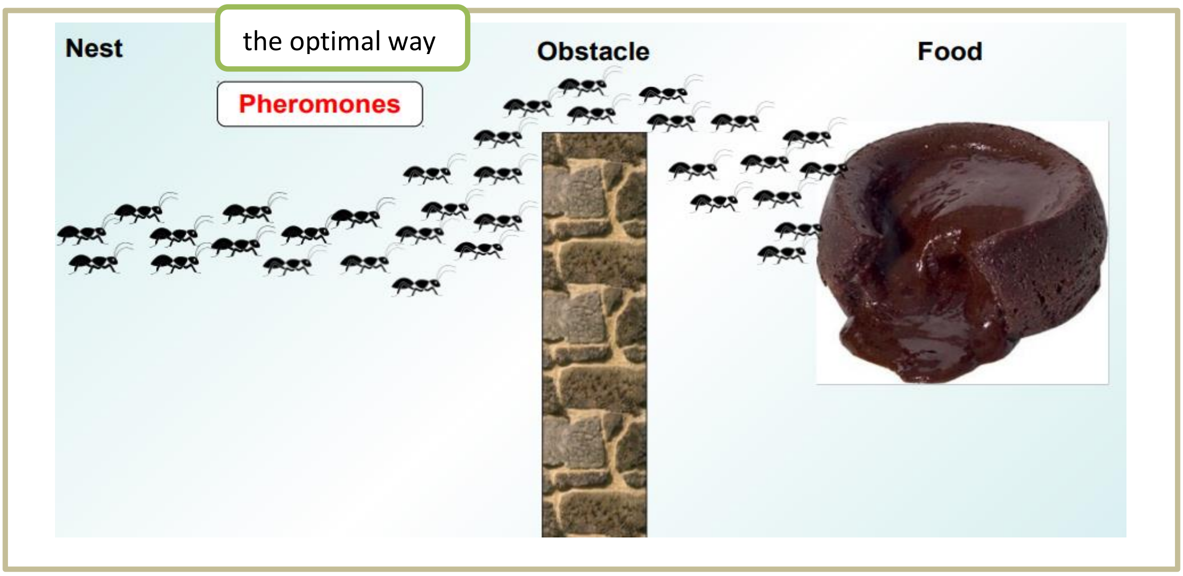
- is stochastic
- is induced by indirect communication (pheromone paths)
- They explore the search space
- They have limited ability to sense local environment
- They act concurrently and independently
- They have high quality solution emerge via global cooperation

When an ant tries to find a route between its nest (anthill) and a food source, it leaves a chemical trail called a pheromone on the ground. The purpose of the pheromone is to guide the other ants towards the target point. However, pheromones trails evaporate and disappear over time unless they are reinforced by more ants. At first, an ant will leave the anthill and begin to wander in a random direction. As it paces around, it lays a trail of pheromone. That's why, when it finally finds some food, it can track its way back to the nest. By doing so, the leaves another layer of pheromone on the path.

Simulation

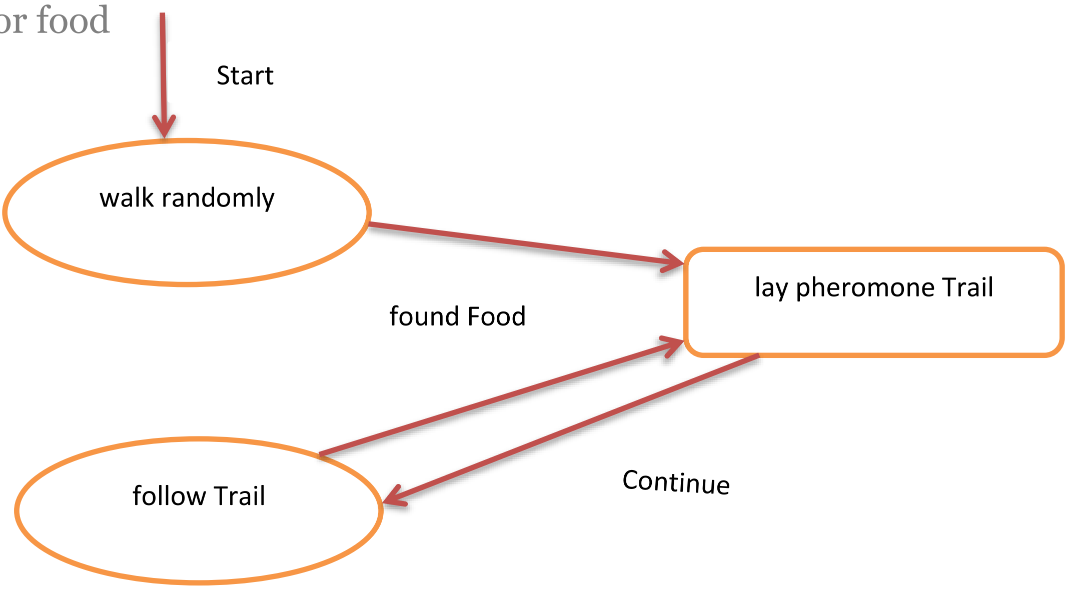

Nest
Obstacle
Food


Nest
Obstacle
Food


Nest
the optimal way
Pheromones
Obstacle
Food

Ant behaviour in a graph:

Quest for food



Example of an ACO algorithm

Suppose that we have a construction project to connect 13 Moroccan cities by a road.

The general algorithm is relatively simple, and relies on a set of ants, each one travels through a path that is possible. At each stage, the ant chooses to move from one city to another according to a few rules:

1- Ants can only visit each city once;
2- The further a city is, the less likely it is going to be chosen (problem of visibility);
3- The greater the intensity of the pheromone track placed on the ridge between two towns, the more likely the route will be chosen
4- Once its journey is completed, the ant deposits more pheromones on all the paths traveled;
5- The pheromone tracks evaporate with each iteration.

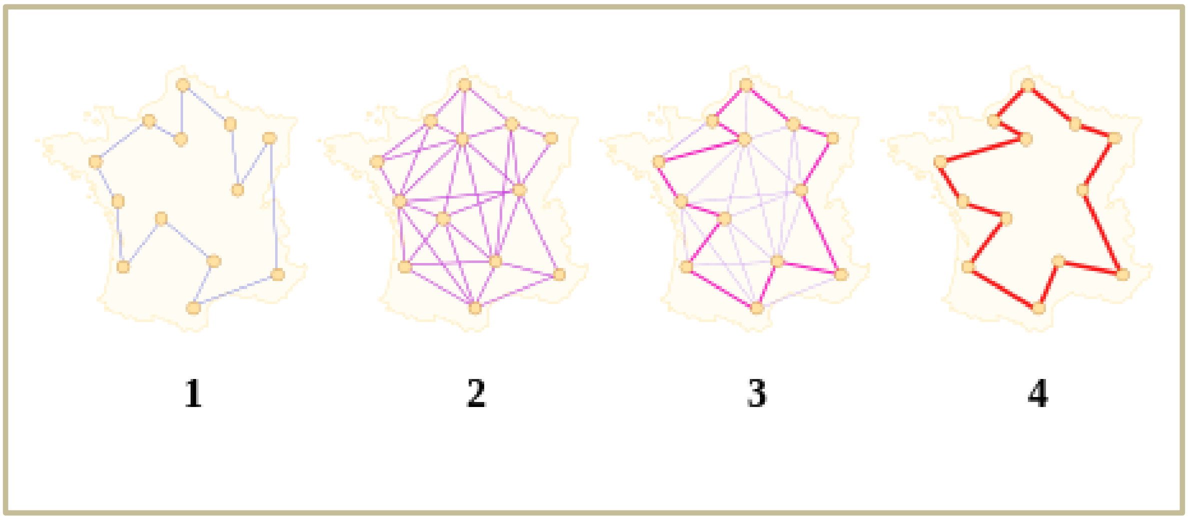
ACO WORKS:

1) An ant chooses a possible route, and deposits a pheromone track there.

2) All the ants will travel a certain number of routes. Each ant depositing a quantity of pheromone is proportional to the quality of the route.

3) Each stop on the best path is more reinforced than the others.

4) Evaporation makes bad solutions disappear

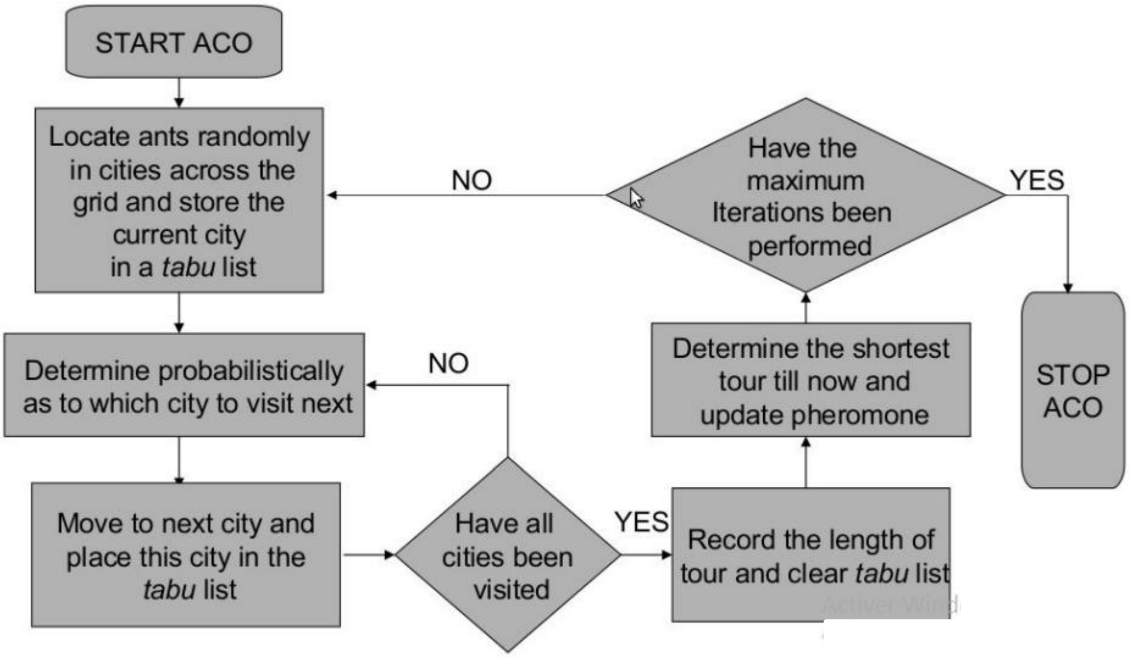


In the first step of each iteration, each ant stochastically constructs a solution. In the second step, the paths found by the different ants are compared. The last step consists of updating the pheromone levels on each road.

ACO ALGORITHM

```
procedure ACO_MetaHeuristic is
   while not_termination do
      generateSolutions()
      daemonActions()
      pheromoneUpdate()
   repeat
end procedure
```

The principle of ACO algorithm:


START ACO
Locate ants randomly in cities across the grid and store the current city in a *tabu* list
Determine probabilistically as to which city to visit next
Move to next city and place this city in the *tabu* list
Have all cities been visited
NO
YES
Record the length of tour and clear *tabu* list
Determine the shortest tour till now and update pheromone
Have the maximum Iterations been performed
NO
YES
STOP ACO

The displacement rule, called the “proportional transition random rule”, is written mathematically in the following form:

$$p_{ij}^{k}(t) = \begin{cases} \dfrac{\tau_{ij}(t)^{\alpha} \cdot \eta_{ij}^{\beta}}{\sum_{l \in J_i^k} \tau_{il}(t)^{\alpha} \cdot \eta_{il}^{\beta}} & \text{si } j \in J_i^k \\ 0 & \text{si } j \notin J_i^k \end{cases}$$

Jik: is the list of possible movements for an ant k when it is in a city i

ηij: the visibility=the inverse of the distance between two cities i and j (1 / dij)

τij (t) the intensity of the track at iteration t.

α and β, control the importance of the intensity and visibility of an edge.

Once the city tour has been completed, the ant k, have a $\Delta\tau_{ij}^{k}($ quantity of pheromone on each edge of its course:

$$\Delta\tau_{ij}^{k}(t) = \begin{cases} \frac{Q}{L^{k}(t)} & \text{si } (i,j) \in T^{k}(t) \\ 0 & \text{si } (i,j) \notin T^{k}(t) \end{cases}$$

where: *Tk (t) :the tour made by the ant k at iteration t. *Q a tuning parameter.

*Lk (t) the length of the path

At the beginning of each iteration of the algorithm, the pheromones deposited by the ants in previous iterations evaporate:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}^{k}(t)$$

m: is the number of ants used for iteration t

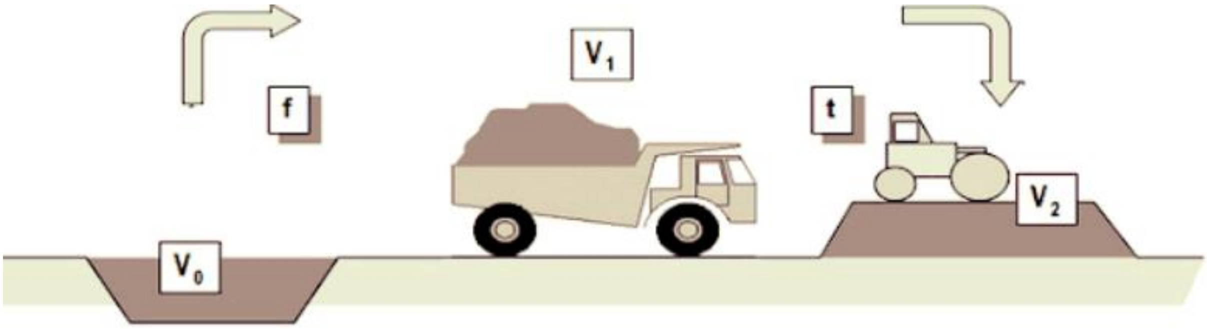
ρ : setting parameter

The added value:

Before applying the ACO Algorithm, it is mandatory to sweep all the possibilities to find the optimal path.

Thanks to this algorithm, the design office can have the most optimal path to connect the different cities. This path is an initial one, that will rectified after eliminating the problems of geo-technics and environment topography.

Moreover, the ACO algorithm can be used to ease the task of moving soil during earthworks in construction sites. In fact, there are always topography problems because the land is never flat. Thus, we have to bring soil to fill up the cuts and excavate the backfills.

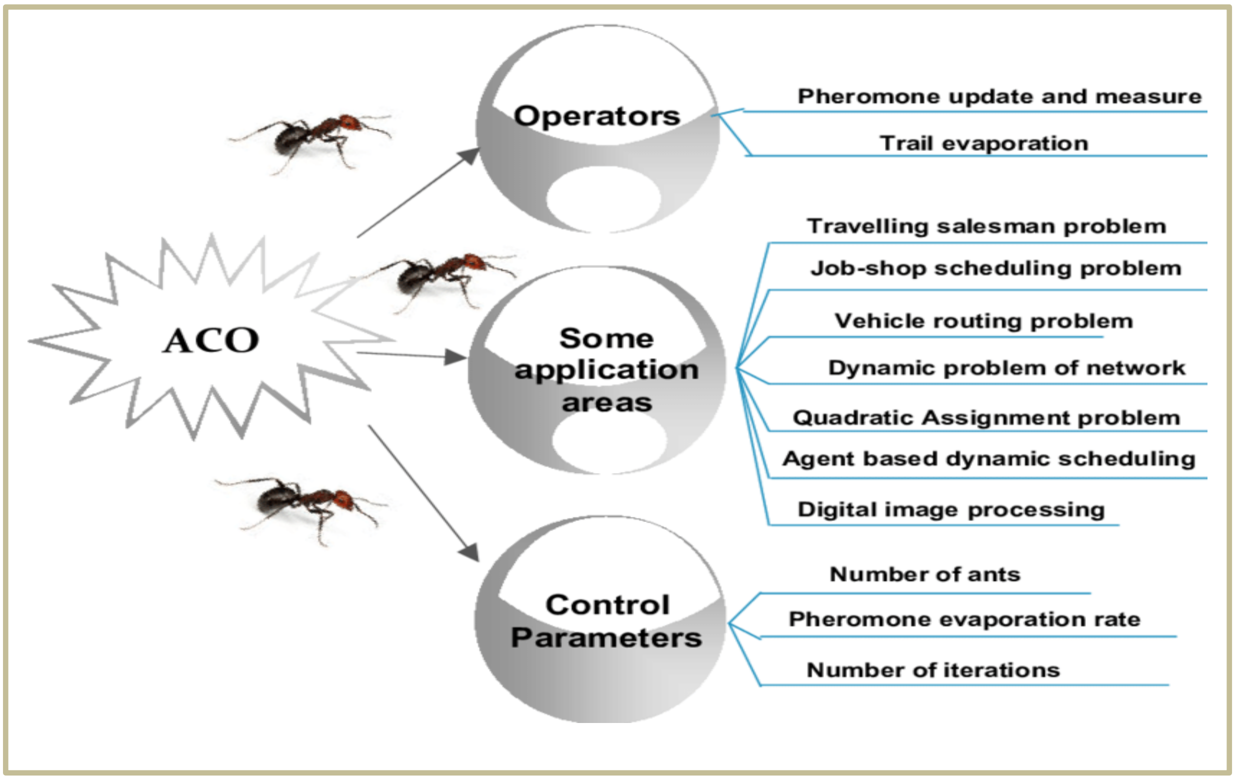


Perspective on ACO enlargement

This optimization technic is included in the field of swarm intelligence (SI). The SI is an integral part of artificial intelligence; it adopts the collective behavior of an organized group of animals or insects as they strive to survive.

Each of us needs to apply optimization in our lives. Even in family-related problems, we always try to find the short way to achieve the best solution. In entrepreneurship, we always want to have the maximum benefits as we launch a project. Thus, the ACO method can be used to solve these and several other problems.

1- Traveling Salesman problems: using ACO Algorithm can help to minimize expenses and maximize the profit.
2- Autonomous car: this algorithm can be used by car robots so that they can choose the optimal way to follow
3- Project management problems
4- Solution of a path planning
5- ACO is a good solution for the delivery companies
6- GPS


ACO
Operators
Pheromone update and measure
Trail evaporation
Some application areas
Travelling salesman problem
Job-shop scheduling problem
Vehicle routing problem
Dynamic problem of network
Quadratic Assignment problem
Agent based dynamic scheduling
Digital image processing
Control Parameters
Number of ants
Pheromone evaporation rate
Number of iterations

Application in Morocco

In Morocco, we still do not have direct applications on the ACO method. However, a lot of studies are done about it. In 2014, during 9th international conference of intelligent systems: theories and applications, they discussed the importance of this algorithm.

In several countries elsewhere, the ACO algorithm proves its efficiency on the Vehicle Routing Problem (VRP) and of its variants, such as:

VRP with time windows for a major supermarket chain in Switzerland; a VRP with pickup and delivery for a leading distribution company in Italy; a time dependent VRP for freight distribution in the city of Padua, Italy, where the travel times depend on the time of the day; and an on-line VRP in the city of Lugano, Switzerland, where customers' orders arrive during the delivery process.

Conclusion

As we discuss this topic of optimization, we realize how our projects can be done more effectively in terms of time and cost. However, planning it and studying it needs to be done by an organization that has well-experienced and well-informed staff in this field, and work attics that will prevent them from providing an incomplete work in terms of quality and effectiveness. And in my opinion, having a government agency to take care of optimization in our country will provide a low-cost study but the quality will probably be questionable due to the economical and sociological issues that the country is facing. In the other hand, if optimization is offered by the private sector, the quality of the studies will definitely be very reasonable because of the competition between all companies in the market, and that each one will try to provide the best quality services in more reasonable prices. Thus, I personally prefer that optimization is done by the private sector.

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